Human Factors Assessments of Environmental Technologies

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Introduction

Federal agencies have devoted increasing attention to environmental technology research and development (R&D) over the past few years. The overall objectives of environmental technology spending include the need for specialized technologies to clean up particularly hazardous or radioactive wastes, interest in reducing risks to clean up workers and the public, reduction of clean up costs, reduced waste management compliance costs, and emphasis on development and utilization of innovative technologies for both domestic and export markets. While the resources devoted to this effort by the federal government are difficult to precisely establish, a July 1995 report entitled "Environmental Technology: Analysis of Selected Federal R&D Programs" by the Office of Technology Assessment (OTA-ITC-155) estimated that $2.5 to 3.5 billion was spent in FY94. While over a dozen federal agencies had environmental technology R&D programs, the Department of Energy had "by far the largest programs" owing to the unique nature of many of the hazards facing the Department's clean up efforts and the shear magnitude of the program to clean up the enormous weapons complex.

It goes without saying that a new environmental technology must be deployed and utilized in the "field" in order to be termed "successful." Effective and efficient utilization and acceptance in the field includes, all too often, additional factors which are most often not addressed by the technology developer: technology specific hazards and/or functional hindrances to those who must use the technology. This is not a problem unique to the environmental technology development community. We, especially in the United States, tend to address such issues after the fact. This approach is further stimulated by the nearly complete lack of safety and health hazard recognition and mitigation training in our engineering colleges' curriculum. These and other significant issues have been addressed by a series of two workshops co-sponsored by DOE and the National Institute of Environmental Health Sciences (NIEHS). The workshops produced a guidance document, "Anticipating Occupational Hazards of Cleanup Technologies: Remembering the Worker" (October 1996) and Technical Workshop reports. The resultant document and reports focus on the occupational safety and health issues that are centered around human interface with new technologies. Interaction beginning with the conceptual phase to that of eventual deployment for actual field operations is discussed. Specific to the environmental

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clean up arena, hazards associated with the deployment of portable incinerators at a number of Environmental Protection Agency (EPA) National Priority List (NPL) waste site remediation projects began to emerge just a few short years ago. This was addressed through a unique agreement between the EPA and the Federal Occupational Safety and Health Administration (OSHA) under the auspices of the EPA-Labor Superfund Safety and Health Task Force.

OSHA fielded a special team to conduct detailed inspections under special procedures of a number of waste sites utilizing incinerator technology. The result was the OSHA "Protocol for Safety and Health Inspections at Superfund Sites" issued on September 30, 1993. Contractors have subsequently utilized this "Protocol" in establishing their safety and health programs at sites utilizing this technology. The result has been a major improvement in safety and health standards compliance, reduced worker injuries, enhanced emergency response preparedness, and reduced "down time."

DOE has not only the largest environmental technology R&D program but has many unique clean up and waste management problems which these technologies seek to address. The result is a broad array of innovative technologies tailored to achieve more effective and efficient operation of targeted tasks. The need to address worker, operator and emergency responder hazards and technology interface issues is, therefore, needed in the broader context of the national technology development program but with even greater emphasis in the DOE program due to its unique dimensions. Of the dozen or more federal agencies involved in environmental technology programs, DOE through the Morgantown Energy Technology Center, is the only one to formally address this need, which it has done through the Cooperative Agreement which is the subject of this paper.

Objectives

The primary objective in the development of new environmental technologies is, among others, to achieve improved clean up efficiency, in less time and at a lower cost. In some instances, an added objective is to remove humans from the high hazard areas in which the technology operates. A constant in the operation of all of these technologies is that operators and maintenance personnel, at a minimum, are required. This man-machine interface and the dimensions of it are broadly termed "human factors." The prime purpose of effective human factors considerations is that operator performance is considered in terms of the variables inherent in the "machine." Technology controls and systems are considered in terms associated with human performance parameters, technology-specific training is considered in terms associated with the most effective operator performance, and system-operator (and maintenance) interactions are considered in terms of operator and equipment safety.

The "technologies" to which the principles of human factors apply, within the more focused context of the DOE environmental technology program, include new remediation equipment, remotely operated (robotic) equipment, and worker protection equipment. Each presents unique human factors challenges. While it is not appropriate to assume that the developers of these technologies are or will be producing technologies which are devoid of human

factors considerations, it is appropriate to characterize most of these development programs as relying on the experience of the design and evaluation staff rather than on a focused and systematic human factors test, evaluation and design approach. The consequence is that new technologies often present operations and maintenance processes which prevent hazards to those engaged in these activities or require that operational procedures vary to the extent that current interfacing practices, such as decontamination of a new worker protective ensemble, fail to function properly and effectively.

The DOE-EM environmental technology development program has been underway for a number of years. As a result, several new technologies are approaching the point where they are ready to be deployed. It is, therefore, far too late in the development cycle to begin to apply the traditional human factors requirements in a systematic way to the DOE development program. The application of mature human factors engineering and test and evaluation programs, such as that employed by DOD over the past few decades, would raise havoc with the DOE program. The problem, then, facing the authors is how to apply human factors assessments within the DOE new technology development community today without major development program disruption while aiding that development community in a value-added manner.

Approach

We have developed a multiple-pronged approach to responding to the challenges associated with becoming value-added participants in the DOE-EM remediation technology development program based upon the current status of that program. The principles involved in our human factors assessment program are:

- Division of the program into two discrete sub-elements:
  1. TYPE I - technologies focusing on the protection of the individual worker.
  2. TYPE II - remediation technology equipment.
- Utilization of human factors testing and evaluation practices for TYPE I technologies in the simulated hazardous waste operations field setting using existing protective practices and procedures as baselines.
- Utilization of established human factors and hazard identification procedures to the TYPE II technologies, as few comparable deployed technologies exist upon which to develop baseline comparative criteria.
- Establishment of an initial emphasis on technology hazard identification, development of hazard mitigation approaches, and development of hazard-specific technology-specific training modules to aid in the safe deployment of the technology.
- Development of a communication network with the DOE technology development community to aid in the consideration of human factors and hazard identification-elimination during earlier phases of the development cycle, where such can be achieved in a far more cost effective manner.

- Development of uniform communication tools such as the Technology Safety Data Sheet (TSDS) and the Emergency Response Data Sheet (ERDS) to aid the developer in transitioning the technology to the contractor-user community in the field.

- Develop an emphasis on the unique emergencies which might occur which are technology specific. This has not been addressed previously in any of the federal environmental development programs.
- Future development of a “new technology approval or certification” program applicable to the DOE Complex.

Project Description

The Human Factors Assessment of Environmental Technologies program conducts human factors, hazard identification, and emergency profiles of new environmental technologies within the DOE-EM technology development program. In summary, technologies to be assessed are selected on the basis of a selection matrix developed by the DOE, Morgantown Energy Technology Center. Assessments may be of the TYPE I or TYPE II category, each of which requires a specific assessment protocol which is developed in draft form and shared with the METC COR and the developer for review and comment prior to finalizing. Working with the technology developer and the METC COR, the technology undergoes testing at the Operating Engineers National HAZMAT Program testing facilities in Beaver, West Virginia or at the developers facilities in selected cases, based upon the technology-specific assessment protocol. Upon completion of the assessment, reports are written and disseminated. Follow-up activities with the developer are offered as a means to aid the developer in addressing issues raised in the assessment, where such is appropriate.

Additional specifics regarding the program details are presented in the following sub-sections.

Technology selection:

Selection of technologies is based upon a 20 point selection matrix developed by DOE-METC with input by EH-5 and others. The selection matrix includes a number of factors associated with the status of the technology and its deployment scope, the establishment of a technology advisory group, a schedule for the development and review of the assessment protocol, and “approval” of the technology. The purpose of the matrix is to establish an orderly, systematic and inclusive approach associated with technology selection and assessment.

Other program elements:

The concept employed by the program is based upon a limited number of diversely experienced program staff, experienced hazardous waste operations field test personnel, and the establishment of formal agreements with other institutions for specialized expertise as needed for specific technology assessments. In addition, one of our agreement partners, Marshall University, provides an independent Human Subjects Review Board (HSRB) which we utilize where test subjects may be exposed to increased risk during the conduct of specific test procedures.

Assessment protocols:

Individual assessment protocols are prepared for each technology assessment. The draft protocol is provided to the METC COR, EH-5, and the technology developer a minimum of 30 days prior to the scheduled assessment. The protocol is revised based upon comments received and issued at least 15 days prior to the assessment.

TYPE I assessments are keyed to comparisons of existing field practices and procedures as baselines and include additional test procedures selected to provide data associated with comparative tasks, for example, with relevant existing technologies. As a result, a TYPE I assessment might include 10 to 20 individual test procedures which may have common procedures compared to another TYPE I technology undergoing assessment and special procedures tailored to the unique features of the technology. Each test procedure is self-contained in that it includes a test milestone chart, details of required support equipment and supplies, test procedure details down to the minute, measurement parameters, test specific data sheet, and list of revisions, if any, based upon utilization in an assessment. These test procedures are maintained as a reference set for use as validated procedures during future assessments. These are included in the test protocol provided to the METC COR, EH-5 and developer prior to the assessment.

After each assessment, the test procedures used in the assessment test schedule are re-evaluated and revised as needed.

TYPE II assessments are based upon the use of existing standard hazard assessment procedures and practices. These include Job Safety Analysis (JSA), Failure Mode and Effects Analysis (FMEA), What-if Analysis, or similar approaches. These approaches are well characterized and discussed in the OSHA Process Safety Management (PSM) standard.

TYPE I Assessments:

TYPE I technologies are technologies developed for the protection of and use by individual workers engaged in hazardous materials operations or activities. Examples include a new fully encapsulating Level A ensemble with integral breathing apparatus and a personal multiple point body monitoring system with remote monitoring for the purpose of heat stress management.

TYPE I technologies are evaluated using standardized test procedures which are based upon the appropriate existing field worker practices and comparative protective equipment. For example, the evaluation of a new protective ensemble would include direct comparison against a current comparable ensemble during the performance of several procedures such as donning, decontamination, doffing, servicing, inspection, maintenance, and performance of “standardized” representative waste site tasks such as manual materials handling tasks. In addition, tailored tasks might be assessed such as vertical and horizontal confined space entry. The ensemble would also be assessed with regard to its effect on specific performance tasks such as the validated performance procedures established for the certification of a heavy equipment operator.

TYPE II Assessments:

TYPE II technologies are unique equipment developed to perform specific remediation functions. These include vitrification technologies, specialized membrane barrier systems (EnviroWall), concrete scabbling equipment, and robotic systems. TYPE II standardized assessment protocols have been developed and are utilized in the evaluation of most technologies of this type. Robotic systems present unique assessment challenges, however which are much closer to the more comprehensive and detailed traditional human factors assessments as the operator-system-equipment linkage is unique, especially when such systems involve the remote operation of heavy equipment physically removed from the operator thus often depriving the operator of a range of operational sensory inputs.

Therefore, while most TYPE II assessments utilize standard assessment procedures, special cases do arise which require development of tailored protocols. As in all technology assessments, communication and coordination with the developer is an important element on a successful assessment.

Reports/Products:

Each technology assessment is followed with a number of reports and products intended to serve a range of diverse audiences. These include:

- A 2 page summary of the assessment results.
- A "chapter" for the specific technology "Green Book".
- A comprehensive technical report.
- A TSDS-Technology Safety Data Sheet.
- An ERDS-Emergency Response Data Sheet.
- A technology-specific training module intended for the on-site training required by the hazardous waste operations and emergency response standard. This module is intended to be used by the contractor employing the technology.
- Supplemental visual aid materials such as video tapes and slides specific to the technology.

In addition, several additional resource and reference materials will become available as the program progresses. These include test procedures and test protocols.

Training Modules:

A unique dimension to this program is the development of technology specific training modules intended to be used by the technology user (contractor) during the conduct of the required site-specific training program. These training modules are keyed to the technology assessment data and utilize video and still photograph's obtained during the assessment tests as training aids. As the Operating Engineers National HAZMAT Program has been the leader in national hazardous waste operations training for over eight years, including within the DOE Complex, the staff is uniquely skilled and experienced in developing such training programs.

Follow-up Activities:

Our experience to-date suggests that technology developers have an unique, indeed state-of-the-art, knowledge about the technical arena in which they are working yet they often lack hands-on experience in the field operations in which their technology will be applied. The focus of this assessment program is intentionally centered on the field operations where these technologies will be deployed owing to the advanced stage of technology development in the DOE program. In that regard, we seek to serve as the first "real world", even though simulated, exposure for a new technology. The human factors assessment staff, our field testers-operators and the cadre of expert resources utilized through agreements have years of hands-on field experience in the remediation sector in addition to the safety and health and emergency response/preparedness professions. We are prepared to work with technology developers, especially after the conduct of an assessment, where we are able to provide assistance to aid the developer in bringing the technology to deployment.

Communications:

The products of the assessment program have been reviewed and discussed previously in this paper as well as the distribution of those products. However, the longer range objective of this program is to stimulate the focus on human factors, hazard identification/mitigation and emergency factors much earlier in the technology development cycle. It has been noted that 70% of the life cycle cost of a technology is locked-in during the conceptual and preliminary design phase. Thus, changes later in the development cycle are expensive which limit change options. In addition, it should be recognized, but generally is not, that the elimination of one safety hazard prior to deployment provides enormous benefit to the contractor using the technology as the contractor does not need to identify that hazard, develop operating procedures to protect workers from exposure to the hazard, provide operator training regarding the hazard, monitor worker compliance with established procedures, and pay additional workers compensation premiums associated with the presence of the hazard.

In order to stimulate this attention during the earlier stages of technology development, unique communication and information approaches must be developed. During the second year of this five year program we will be devoting attention to this issue. Those in the DOE technology development community are urged to provide us your ideas and recommendations as to how we might approach this challenge.

Future:

There is a growing interest within DOE in the "certification" or "acceptance" of new technologies as a pre-requisite to deployment. EPA, having a somewhat similar new technology program termed the Superfund Innovative Technology Evaluation (SITE) Program, has funded pilot programs in California to develop such a technology certification program. A few other states are considering such programs as well. These certification programs, however, are technology efficacy certification programs. They do not consider technology human factors, hazards, or emergency factors all of which can effect worker and public well-being and

operational costs.

We propose to host a workshop to address this issue during this second year of the agreement as a means of gaining initial input and perspective from the DOE environmental technology community.

Results

Results during the first year of the cooperative agreement have been devoted toward a fairly complex program launch effort exacerbated by the budget disruptions from the Congress affecting the first several months of FY96. None-the-less, the following accomplishments have been achieved:

Overview:

- Commencement of the construction program for the testing facilities at the Mine Safety and Health Administration (MSHA) Mining Academy in Beaver, West Virginia. Construction is now scheduled for completion in the early spring of 1997.
- Development of TYPE II technology assessment protocols.
- Development of a wide range of test procedures for TYPE I assessments.
- Review, selection and development of agreements with key external expert resource institutions.
- Completion of ten TYPE II technology assessments.
- Development of a format and content of the three reports required for each assessment.
- Preparation of 28 draft assessment reports, receipt of review comments, and preparation of the final reports.
- Preparation of a preliminary TYPE II technology specific training module with video and slide support materials. The review process will aid in assuring appropriate content and format for use by the contractor target audience. Thereafter, such training modules will be developed for the remaining technologies as appropriate considering the technology development cycle stage and the anticipated need to conduct additional assessments.
- Completion of one TYPE I technology assessment.
- Preliminary interfacing with a recently awarded robotics work station development contractor.
- Continued interaction with most of the developers of technologies already evaluated during this first year.
- Development of a preliminary Communication Plan.
- Development of the content and format of the Emergency Response Data Sheet, including the assessment parameters for completion of the ERDS.

Specific Assessment Highlights:

EnviroWall: The EnviroWall technology involves the placement of a sub-surface ground water barrier membrane and ground water collection point utilizing specialized fixtures set in excavated trenches and subsequently removed after membrane placement. Primary hazards are

those normally associated with construction excavation activities. Additional operational hazards may arise depending upon the nature of the soil in which the barrier is placed and whether the workers placing the membrane system are required to wear protective equipment.

Robotics: Three activities have been undertaken which involve robotics control systems. Two involved Lockheed-Martin developments termed the T-Rex (excavator) and the D6 Dozer. Both of these interactions were at the Lockheed-Martin facilities in Baltimore, Maryland, for which only a very limited time envelope was available. As a consequence, only one report was prepared for each of these devices and the reports are termed "Observations/Recommendations". Subsequent interactions with this developer have occurred associated with these projects. The third robotics activity involved preliminary discussions with Carnegie-Mellon regarding their recently awarded contract to develop a standardized robotics work station.

Surface removal technologies: Seven comprehensive assessments were conducted at Florida International University (FIU) involving surface removal technologies. These included the 3M Heavy Duty Roto Peen, Concrete Cleaning, Inc.'s Centrifugal Shot Blast, Stephens Environmental Co.'s Ultra-High Pressure Water system, LTC Americas, Inc.'s Concrete Scabbling and Metal Descaling, and Pentek, Inc.'s Concrete Scabbling and Metal Descaling. Three reports, as described earlier, have been prepared and issued for each of these assessments. These technologies are considered by FIU to be at the benchmark stage with subsequent advanced devices to be developed. In that regard, the human factors and hazard assessment reports serve the function of identifying issues of concern which may be addressed in the next generation equipment.

Not unexpectedly, the primary hazards associated with these technologies involve excessive noise, dust exposures and a number of technology specific human factors-operational issues such as the excessive ergonomic stresses associated with the operational posture and the back-pressure from the nozzle of the Ultra-High Pressure lance.

We are currently working with FIU to establish a schedule for the next round of assessments.

Advanced Worker Protection System: The assessment of the only TYPE I technology tested during this first year has just recently been completed. The three draft reports associated with this assessment will be issued by the end of October 1996. This technology applies a number of unique and innovative approaches to providing the individual worker respiratory protection, skin protection and thermal cooling. Not unexpectedly, this first intense venture outside the laboratory into the simulated waste site field setting evidenced a few difficulties, most associated with the operational interface between the three primary components of the ensemble: cooling garment, chemical protective garment and respirator. We are continuing to work with the developer, Oceaneering Space Systems, to provide assistance in addressing these issues.

Benefits

The potential benefits associated with this human factors assessment program accrue to a wide range of entities. To:

- Technology developers who will have the opportunity to “field test” their equipment before actual deployment.
- Technology developers who may see greater confidence among the DOE clean-up technology selectors to utilize newly developed technologies.
- DOE field remediation program managers who may benefit from reduced down-time and loss of production and increased costs associated with bringing new technologies on-line.
- Operators and maintenance personnel who will face less risk associated with the technology hazards and unique operational requirements.
- Operators who will be able to effectively and efficiently operate the technology while wearing protective ensembles in a hazardous environment.
- Operators who will be able to effectively and efficiently operate robotically controlled equipment.
- Contractors who will have greater confidence in new technologies based upon technology specific data to aid in operations, maintenance, and emergency response planning and the training programs provided with the technology.
- The emergency response community which will be prepared to respond to a new technology unique emergency properly and effectively.
- The DOE through reduced costs, reduced worker injuries and illnesses, and more timely deployment of new technologies.
- Over the longer term, increased ability of technology designers to recognize and eliminate human factors problems and hazards early in the development cycle thus providing substantial benefit to the end users and reducing liability potential.
- Reduce, and in many instances eliminate, the need for lengthy and costly hazard analysis and training programs.
- Reduce or eliminate workman’s compensation and costs incurred with training replacement workers.
- Establish means of tracking injury and illness, as well as reducing risks by amending modulated training programs.

Future Activities

The plans for the second year of the cooperative agreement include the assessment of ten technologies and the issuance of reports on those assessments. We will be working with the METC COR to target those technologies and develop the appropriate assessment protocols. There are a number of related activities which will be pursued during this second year as well. These include the full development of an operational HSRB with Marshall University which will permit us to conduct more advanced field assessments of TYPE I technologies, continuing relationships with technology developers to aid in their development efforts, advancement of our Communication Plan to extend information about the human factors issue to the broader DOE

technology development community, and the hosting of a work shop to develop preliminary concepts for a DOE new technology certification or approval process. We will, as well, move into and bring to operational status the new facilities currently under construction.

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